Probing dark matter with stellar-stream density fluctuations in the LSST era

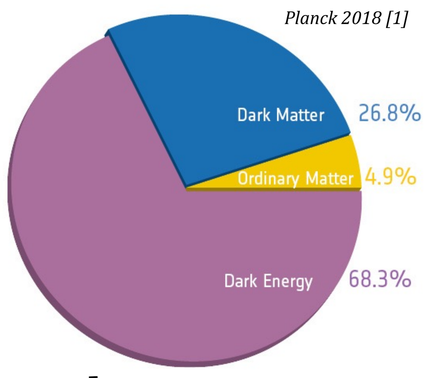
***Matthieu Pélissier*[1], *Alex Drlica-Wagner*[2], *Peter Ferguson*[3], *Marine Kuna*[1], *David Maurin*[1]**

[1]CNRS-LPSC Grenoble, France; [2]Fermi National Accelerator Laboratory; [3]DiRAC Institute, Department of Astronomy, University of Washington

Imprints of dark matter on stellar streams

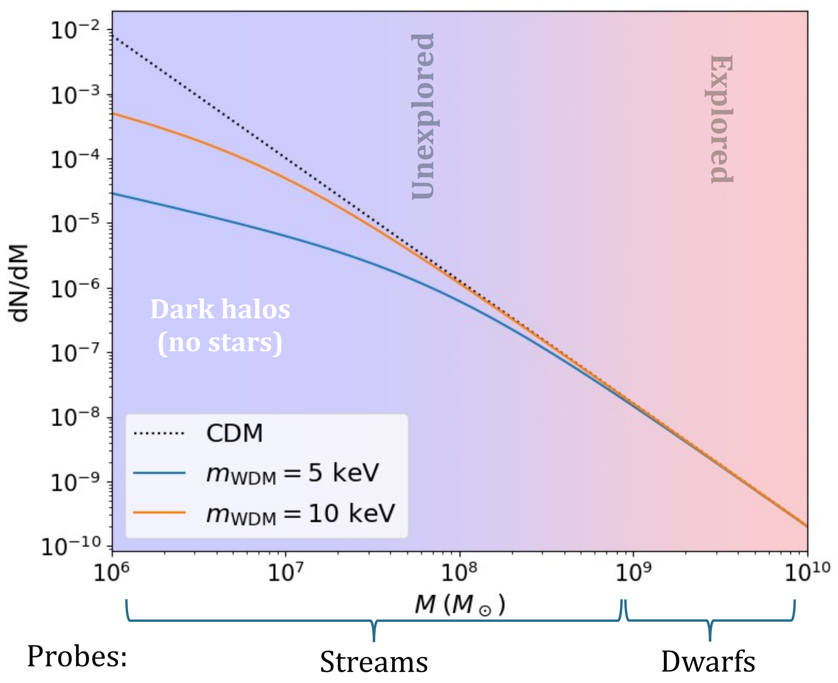
What is the nature of dark matter (DM)?

- Concordance **cosmological model**
- Only **gravitational** observations
- Unknown nature



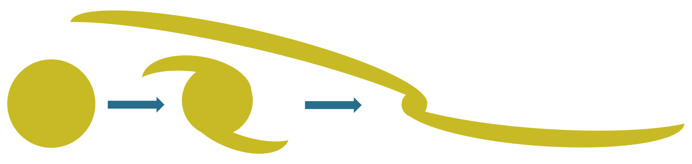
Milky Way DM distribution: **smooth halo + substructures**

Different DM models predict different **subhalo** populations: Cold Dark Matter (CDM, Standard Model hypothesis), Warm Dark Matter (WDM) ...



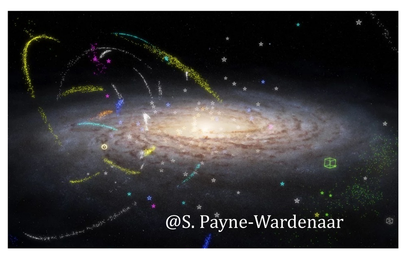
What are stellar streams?

Globular cluster or dwarf galaxy **distorted by tidal effects** during their revolution around our Galaxy



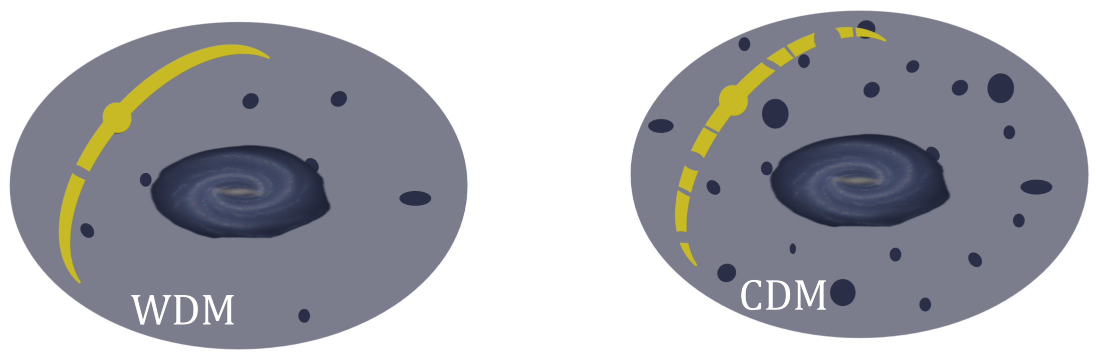
Key numbers:

- Tens of kpc long
- Contains thousands of stars
- More than 100 known streams in our Galaxy



Probing DM with stellar streams

Impacts of **subhalos** can create **disturbances in streams**



Streams as a new probe to study the **substructure population** of the dark matter halo ($10^6 - 10^9 M_\odot$) **to differentiate** models [2]

Tens of predicted CDM subhalo encounters per stream

Statistical study to **characterize** the **population** of **dark matter substructures** [3]

Stellar streams in LSST

Rubin/LSST

- **Optical** ground-based 10-year survey
- First images in **April 2025**
- **Survey** starting in **2026**
- Magnitude limit = 27 (vs 20 for previous survey *Gaia*)
- 10^{10} stars to be detected

New streams and gaps could be detected [4]

Observing conditions and instrumental **systematics** can **introduce artificial** stream density **fluctuations**

- Non-uniformity of the survey depth
- Imperfect star-galaxy separation
- Extinction due to dust

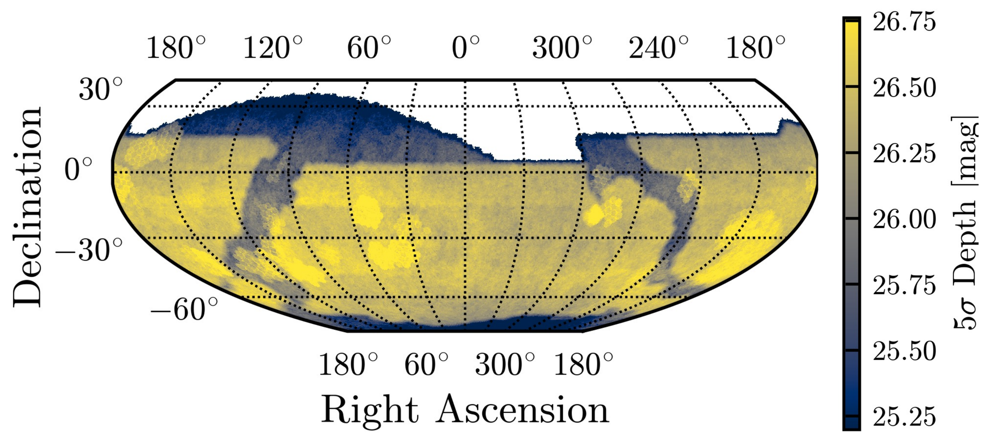


Fig: 4-years depth map, r band

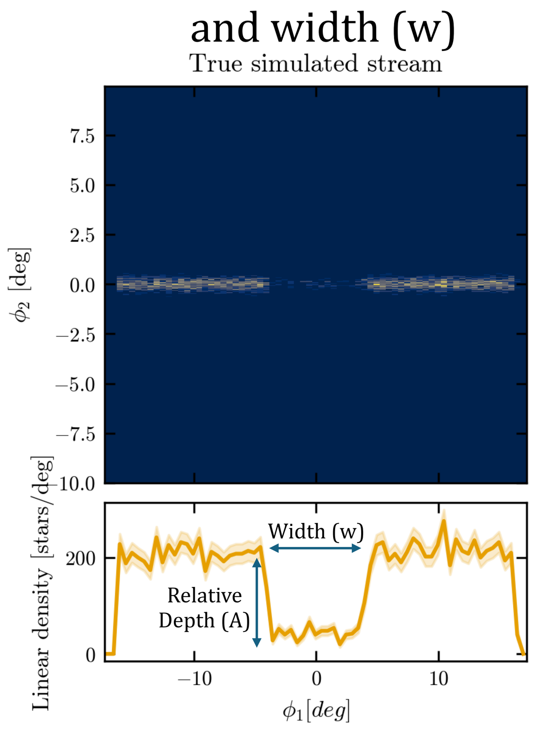
Goal: **simulate** realistic stellar **streams observation** for density **fluctuations measurement**

Official DESC project (Dark Energy Science Collaboration)

Generate LSST-like stream observations

Parametric model

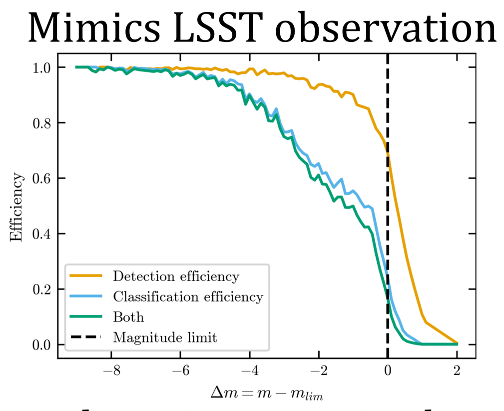
Gap defined by depth (A) and width (w)



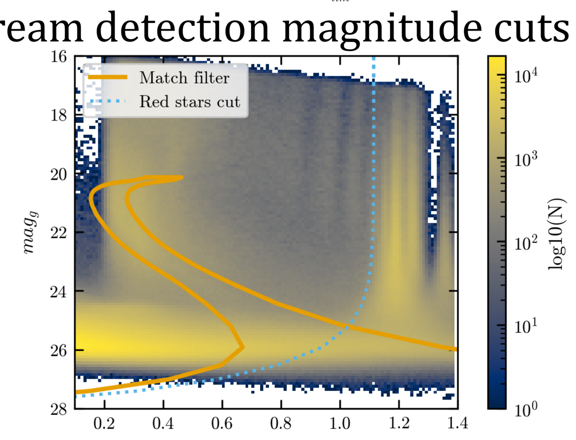
ϕ_1, ϕ_2: sky coordinates in stream frame

StreamSim[5] package (co-developer)

Mimics LSST observation

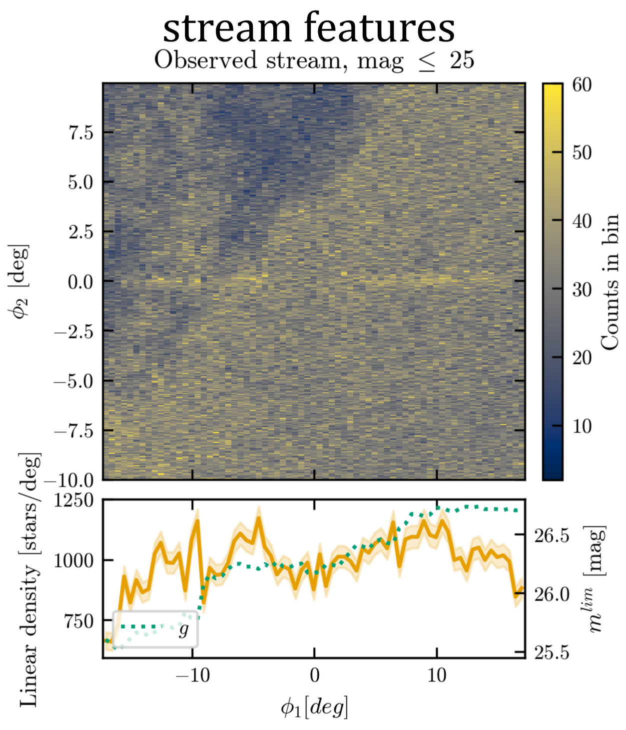


Stream detection magnitude cuts



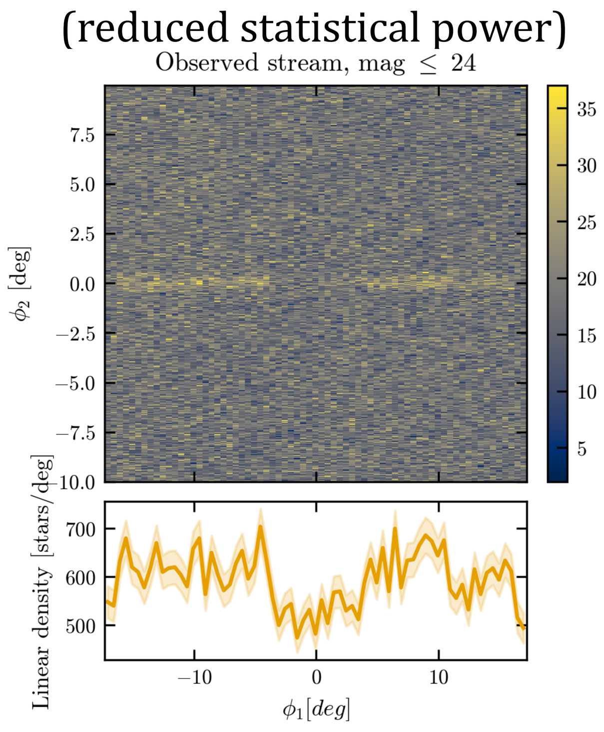
Mock data

Observational systematics hide stream features

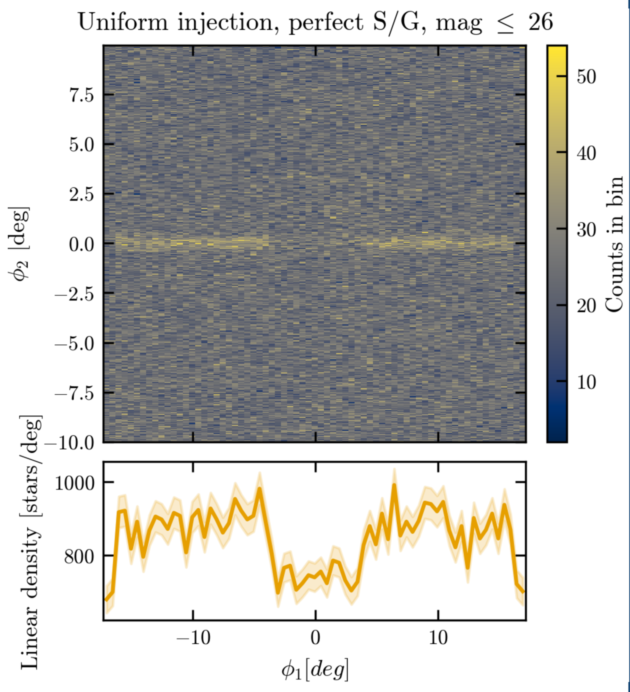


Simple systematics mitigation

Bright magnitude cut (reduced statistical power)



Uniform survey (no systematics)

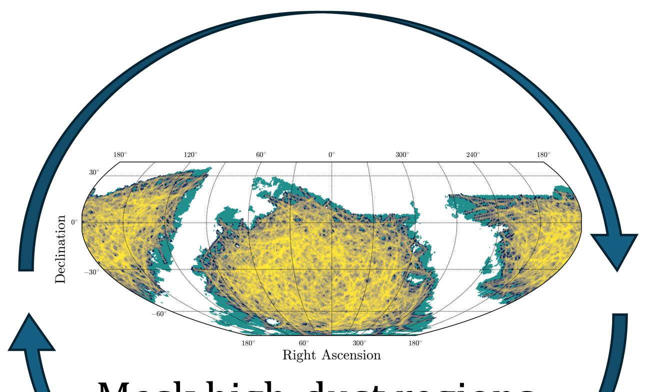


Recover survey **homogeneity** with **bright** magnitude cut

Fluctuation detection efficiency

Goal: estimate **lowest density fluctuations** measurable **above LSST systematics**

Depth (A), width (w) → **Simulated observed data** → **Power spectrum $P(k) = |FT(\rho)|^2$** → **Fit $P(k)$** → **Likelihood ratio $R = -2log\left(\frac{\mathcal{L}(A=0,\theta|data)}{\mathcal{L}(A,\theta|data)}\right)$** → **Fluctuation detection**



Mask high-dust regions to isolate systematics

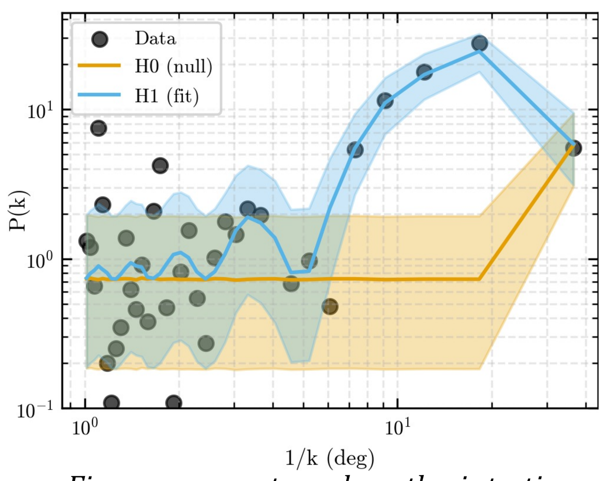
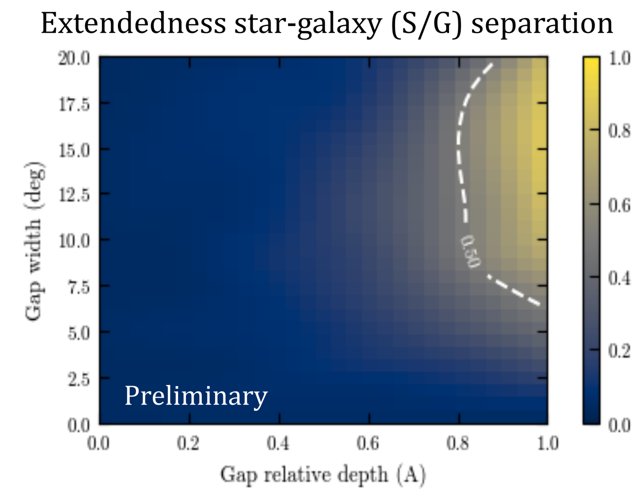
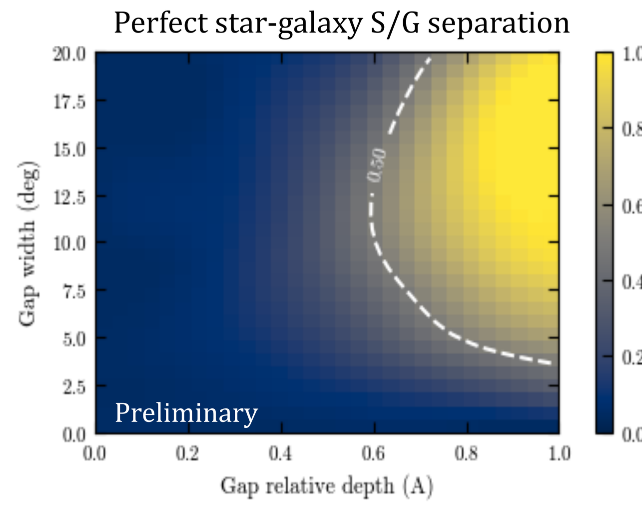


Fig: power spectrum hypothesis testing

Statistical study over the full LSST footprint → Estimate **detection efficiency** at given (A, w)

Detection **efficiency maps** for a given **gap** (depth, width)





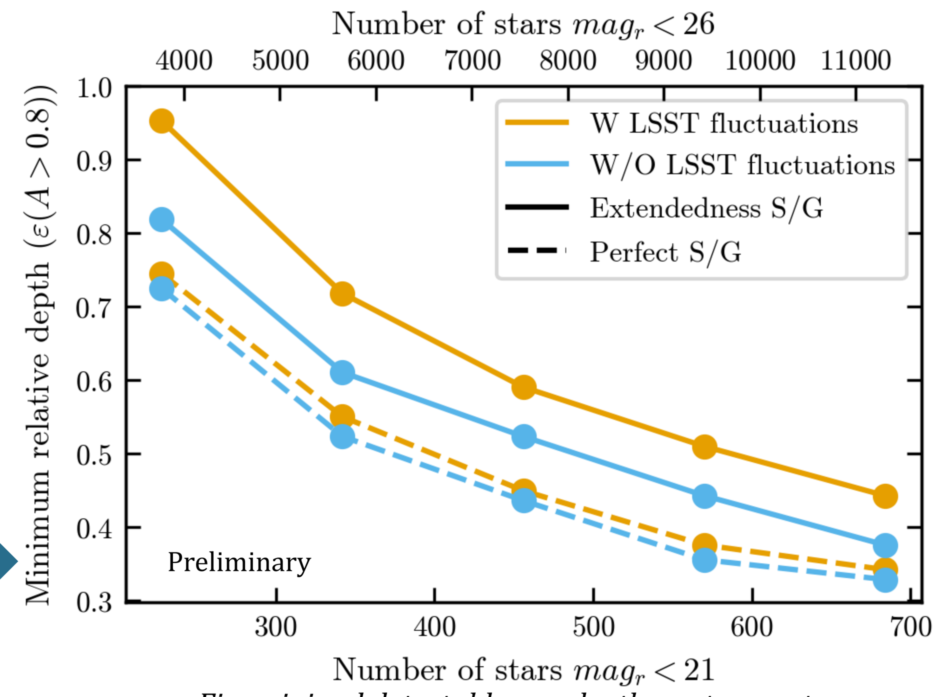


Fig: minimal detectable gap depth vs. stream stars

Conclusion

- **Systematics** and star–galaxy separation strongly **impact density-fluctuation** measurements
- Converting to subhalos properties: **systematics increases** the **minimum detectable subhalo mass** by ~ factor 2(ongoing work)
- DESC **publication** in preparation

References

1. Planck results. VI. Cosmological parameters (2018)
2. R. A. Ibata et al., MNRAS, 332.4 (2002)
3. J. Bovy et al., MNRAS, 466.1 (2017)
4. A. Drlica-Wagner et al., arXiv e-prints, p. arXiv: 1902.01055 (2019)
5. https://github.com/LSSTDESC/stream_sim

Rencontres de Moriond
03/2026